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**(54) Method and apparatus for handling nested interrupts**

Verfahren und Vorrichtung zur Verarbeitung von verschachtelten Unterbrechungen

Méthode et dispositif pour le traitement des interruptions imbriquées

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(73) Proprietor: **MOTOROLA, INC.**  
**Schaumburg, IL 60196 (US)**

(72) Inventors:  
• **Cohen, Robert B.**  
**Austin, Texas 78745 (US)**  
• **Garner, Robert E.**  
**Austin, Texas 78748 (US)**

(74) Representative: **Lupton, Frederick et al**  
**Motorola European Intellectual Property,**  
**Midpoint,**  
**Alencon Link**  
**Basingstoke, Hampshire RG21 1PL (GB)**

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## Description

### Field of the Invention

The present invention relates, in general, to a method and apparatus for preventing recursion jeopardy. More particularly, the invention relates to a method and apparatus for handling exception processing, such as interrupts, and for preventing recursion jeopardy in microprocessors.

### Background of the Invention

In apparatus such as microprocessors and other digital processors, a central processing unit (CPU) is utilized for the processing operations. The CPU includes an on-chip register set which is utilized by the CPU during both normal operation and exception processing, in a manner well known to those skilled in the art. Whenever any prior operation is interrupted by an exception process such as an interrupt operation, there is a recursion jeopardy problem because the interrupt processing program will use the same registers and may change some of the values therein. The conventional solution to the problem is to save in a memory (also referred to as "stacking") the current values of some or all of the registers prior to beginning the processing of the interrupt and reading those saved values back into the registers from memory (also referred to as "unstacking") when interrupt processing is complete. This solution is time consuming and requires relatively extensive software support. However, this solution is theoretically capable of handling an unlimited number of "nested" interrupts (*i.e.*: interrupts which interrupt other interrupt programs).

Some microprocessors provide several, alternate on-chip register sets (also known as register banks) for use during interrupt processing. An interrupt program simply uses a different set of registers than was being used by the interrupted program, thus avoiding the need to stack the register contents. This approach is very costly in terms of the silicon area when the problem of nested interrupts is considered. Duplicating all the necessary registers in order to permit a reasonable number of nested interrupts may well require an unreasonable number of registers.

Further, some mechanism must be provided, even in a machine having multiple register banks, to determine when all banks are in use (when recursion jeopardy exists) and to provide some solution to the problem.

United States Patent No. 4,434,461 describes a microprocessor that switches over to a duplicate program counter, duplicate general purpose registers, and duplicate zero and carry flags during interrupts. As a result, interrupts are processed by switching back and forth between the program counter register, general purpose registers, and zero and carry flags and their duplicates.

### Summary of the Invention

In accordance with a first aspect of the invention there is provided a digital data processor as claimed in claim 1.

In accordance with a second aspect of the invention there is provided a digital data processor as claimed in claim 5.

In accordance with a third aspect of the invention there is provided a method of operating a digital data processor as claimed in claim 6.

### Brief Description of the Drawings

FIG. 1A is a simplified functional block diagram of a digital data processor system which comprises a particular embodiment of the present invention; FIG. 1B is a diagram of registers contained within the digital data processor system of FIG. 1A; FIG. 1C is a diagram of bits contained within two particular registers shown in FIG. 1B; FIG. 2 is a flow chart illustrating an interrupt nesting example utilizing the present apparatus and method; and FIG.s 3A and 3B are state diagrams using status bits to distinguish the various states and representing two possible ways in which the digital data processor can handle interrupt processing and avoid recursion jeopardy.

### Description of the Preferred Embodiment

The terms "set" and "clear" will be used when referring to the rendering of a status bit or similar apparatus into its logically true or logically false state, respectively.

Referring to FIG. 1A, a digital data processor system 10 is illustrated which in this simplified form comprises a semiconductor chip 12 having a CPU 14 containing a normal register set 16, an alternate register set 18, unprime registers 20, prime registers 22, and other registers 24. The CPU is connected to a bus 40 which is also connected to an off-chip memory stack 50. It will of course be understood that in some specific processor systems the memory stack 50 and the bus 40 may be included on-chip and the off-chip memory stack is illustrated for example only. It will also be understood that memory stack 50 requires bus 40 operation to be accessed and that accessing register sets is a high speed operation while accessing the memory stack across the bus 40 is a relatively slow operation. Therefore, it is desirable to utilize the register sets as much as possible during processing and to utilize the memory stack only when essential.

In digital data processor system 10 there are multiple interrupt levels which determine whether a given interrupt has priority over any other interrupt. Thus an interrupt with a higher priority will get processed more quickly than an interrupt with a lower priority which must

wait for processing. The concept of interrupt priority is well known to those skilled in the art. Although this particular embodiment deals with the recursion jeopardy that can occur when multiple interrupts try to use the same register resources, it should be understood that the disclosed invention could be used to prevent recursion jeopardy in any storage means on any type of integrated circuit.

Digital data processor system 10 utilizes two types of interrupts: conventional interrupts and fast interrupts. The type of interrupt determines whether the interrupt processing routine will default to using the normal register set 16 or the alternate register set 18. Conventional interrupts default to using the normal register set 16 and fast interrupts default to using the alternate register set 18. The interrupt type does not affect the priority scheme. A conventional interrupt will interrupt normal operation or any other interrupt which has a lower priority level. Likewise, a fast interrupt will interrupt normal operation or any other interrupt which has a lower priority level.

Referring to FIG. 1B, the normal register set 16 consists of eight data registers (D0-D7) and eight address registers (A0-A7), with the last address register A7 also acting as a user stack pointer. The alternate register set 18 duplicates the registers in the normal register set 16. The CPU will access and use either the normal register set 16 or the alternate register set 18, but never both register sets at the same time. From the viewpoint of a user writing software for the CPU, which register set is being used is relatively transparent. That is, the user may simply direct that a particular instruction use data register D2 as a source of an operand or destination of an operation. Hardware will determine whether the D2 register of the normal set 16 or the D2 register of the alternate set 18 will be accessed. As is familiar to users of any of Motorola's 68000-family of microprocessors (e.g.: MC68000, MC68010, MC68020 and MC68030, all available from Motorola, Inc. of Austin, Texas), the CPU operates in either a user mode or a supervisor mode. The mode of operation is controlled by a bit located in the status register SR.

Again referring to FIG. 1B, the unprime registers 20 consist of a status register (SR), a context switch control register (CSC) 31, and a program counter (PC). Referring to FIG. 1C, the prime registers 22 duplicate the unprime registers 20 with the exception of the FO (Fast Interrupt Occurred) status bit 26, the FF (First Fast Interrupt) status bit 28, and the CF (Current Fast Interrupt) status bit 30 in the CSC register 31. The FO status bit 26, the FF status bit 28, and the CF status bit, are not duplicated. The CPU will access and use either the unprime registers 20 or the prime registers 22, but never both register sets at the same time. An access to either the CSC register 31 or the CSC' register 32 will result in the same FO status bit 26, FF status bit 28, and CF status bit 30 being accessed. The A/N bit 34, however, is

described below.

Referring to FIG. 1C, the A/N bit 34 is located in CSC register 31. A duplicate A/N' bit 36 is located in CSC' register 32. When the CPU 14 is using the unprime registers 20, only the A/N bit 34 can be accessed. Similarly, when the CPU is using the prime registers 22, only the A/N' bit 36 can be accessed. Neither the A/N bit 34 nor the A/N' bit 36 can be accessed by software in user mode, however, the CPU 14 hardware can always read the status of these bits. In this particular embodiment, either the A/N bit 34 or the A/N' bit 36 can be accessed as a control bit in supervisor mode to force the CPU to use the corresponding set of normal registers 16 or alternate registers 18. This is an additional feature that is not required to practice the present invention. So for the sake of clarity, it will be assumed in the remaining explanation that the A/N bit 34 and the A/N' bit 36 are being used as read-only status bits by the CPU 14 hardware.

Either the A/N bit 34 or the A/N' bit 36 indicates whether the CPU 14 is presently using the normal register set 16 or the alternate register set 18. A "zero" value indicates that the alternate register set 18 is being used and a "one" value indicates that the normal register set 16 is being used. If the A/N bit 34 or the A/N' bit 36 is stacked along with information from either the normal register set 16 or the alternate register set 18, the CPU 14 hardware or a software routine can use the A/N bit 34 or the A/N' bit 36 when it unstacks to determine whether the information should be restored to the normal register set 16 or to the alternate register set 18.

The unprime registers 20 are only used when no fast interrupt has begun processing. Once a fast interrupt is received and begins processing, the prime registers 22 are used exclusively for the first fast interrupt and any new incoming fast or conventional interrupts. The CPU 14 does not return to using the unprime registers 20 until the first fast interrupt has been completed and there are no more fast interrupts to process. Also, every time that a higher priority interrupt interrupts the processing of a lower priority interrupt, the prime registers 22, which contain the A/N' bit 36, the FO status bit 26, the FF status bit 28, and the CF status bit 30, are automatically stacked to the memory stack 50 by the CPU 14 hardware. This stacking is always required because the prime registers 22 contain information that is necessary to complete the processing of the lower priority interrupt.

In this particular embodiment, there is an important distinction between the unprime 20 and prime 22 registers as compared to the normal 16 and alternate 18 register sets. The CPU 14 uses the prime registers 22 during all interrupt processing once a fast interrupt has been received, whereas the CPU 14 can use, depending on the type of interrupt, either the normal register set 16 or the alternate register set 18 during interrupt processing. This distinction was made for convenience in this particular embodiment. Because the registers comprising the unprime 20 and prime 22 registers are

registers containing information that must be stacked any time a new higher priority interrupt is received, the CPU 14 in this particular embodiment automatically stacks these registers when there is recursion jeopardy in order to save software processing time. The normal 16 and alternate 18 register sets, on the other hand, are data and address registers that only require a particular register to be stacked if the new higher priority interrupt is going to alter the information in that particular register. Thus the stacking of any registers in the normal 16 and alternate 18 register sets is left to the programmer using software control so that there is no processing time wasted on unnecessary stacking.

Referring to FIG. 1B, the other registers 24 consist of registers which are not duplicated and can be used by the CPU 14 at any time regardless of whether or not the CPU 14 is carrying out normal operations or interrupt processing. Because there is no duplication, anytime that an interrupt routine will affect the data in any of these other registers 24, the interrupt routine must stack those registers that it is going to affect. If there is the possibility that one software routine using one or more of the other registers 24 may interrupt another software routine using one or more of the other registers 24, then there is always the possibility of recursion jeopardy. There are no status bits or control circuitry to aid in handling recursion jeopardy problems for the other registers 24. Because there is no way to determine whether or not recursion jeopardy actually exists, each software routine using the other registers 24 must always assume that there is recursion jeopardy and must stack any of the other registers 24 that the interrupting software routine will affect. In this particular embodiment, the other registers 24 are ones that are only used when the CPU 14 is in supervisor mode. Other registers 24 are registers that will rarely need to be stacked in most applications, and thus there was no reason to waste silicon area duplicating the registers and no reason to waste processing time having the CPU automatically stack these registers.

It is apparent that there are three "classes" of register described: those which are duplicated and always stacked automatically (the unprime and prime registers), those which are duplicated but stacked only as necessary and under software control (the normal and alternate registers) and those which are not duplicated and are stacked only as necessary and under software control (the other registers). It is to be understood that there are many different register configurations that could employ the present invention. The register configuration described in this specification is just one configuration out of many possible register configurations that could be used. For instance, the description above could be readily extended to the case of multiple register banks. In this case, there could be several nested interrupts before recursion jeopardy occurs. The principles, however, remain the same. Also, it is to be understood that it is possible to use either software instructions or

CPU 14 hardware to stack and unstack information from memory stack 50.

Referring to FIG. 1C, the FO status bit 26, the FF status bit 28, and the CF status bit 30 are all read-only status bits which are automatically set by operation of CPU 14. A first of the three status bits, FO (Fast Interrupt Occurred) 26, is set if one or more fast interrupts have been initiated but have not yet been completed. This bit indicates a recursion jeopardy in the present system and remains set until cleared upon the completion of all current fast interrupt processing. A second of the three status bits, FF (First Fast Interrupt) 28, is set when a fast interrupt occurs and there are no other fast interrupts being processed (i.e. it is the first fast interrupt). It is cleared for all subsequent interrupts after the first fast interrupt. A third of the three status bits, CF (Current Fast Interrupt) 30, is set only while CPU 14 is in the fast interrupt mode of operation. The CF status bit 30 can be used by both hardware and software to determine whether the interrupt being processed is a conventional interrupt or a fast interrupt. Thus the three status bits, FO status bit 26, FF status bit 28, and CF status bit 30, generate and maintain information on the state of recursion jeopardy of normal register set 16, alternate register set 18, unprime registers 20, and prime registers 22. The status bits can be monitored by CPU 14 and utilized during programming to provide optimum use of normal register set 16, alternate register set 18, unprime registers 20, prime registers 22, and memory stack 50.

In the present embodiment wherein normal register set 16 is utilized for normal operation and conventional interrupts and alternate register set 18 is utilized for fast interrupts, there may be recursion jeopardy if one interrupt is interrupted by another interrupt, because the second interrupt may try to utilize the same register set as the first interrupt without saving the information in the registers. By providing status regarding the interrupts, software can be written: (1) to detect that information stored in part or all of a register set must be saved to the memory stack 50; (2) to detect that the previously stored information must be unstacked and restored to one or more registers; and (3) to detect what type of interrupt is currently being processed. There is also recursion jeopardy when a conventional interrupt is received during normal operation because the processing of the conventional interrupt will use the same normal register set 16 and the same prime registers 22. There is no recursion jeopardy when a first fast interrupt is received because the first fast interrupt will cause the CPU 14 to switch from using the normal register set 16 to using the alternate register set 18 and to switch from using the unprime registers 20 to using the prime registers 22 for the first time.

In this particular embodiment, the CPU 14 hardware uses the FO status bit 26, the FF status bit 28, and the CF status bit 30 along with the interrupt type of a pending interrupt to determine whether to switch between the unprime registers 20 and the prime registers 22, or

whether to stack the prime registers 22 and then use the prime registers 22. This determination could also be accomplished in software. In this particular embodiment, the CPU 14 switches to using the prime registers 22 when the first fast interrupt is received. If any additional fast or conventional interrupts are received before that first fast interrupt has finished processing, the CPU will continue to use the prime registers 22. The CPU 14 does not switch back to using the unprime registers 20 until all of the pending fast interrupt routines have finished processing.

CPU 14 hardware never stacks any of the registers in the normal register set 16 or the alternate register set 18. Any stacking of these registers that is required is left up to the user to perform in software. The CPU 14 hardware routine, however, does determine whether to switch between the unprime registers 20 and the prime registers 22 based upon whether the CPU 14 is in normal operation, processing a conventional interrupt, or processing a fast interrupt. Once again, the decision of whether to stack a set of registers or whether to switch to another set of registers could also have been accomplished using either software or CPU 14 hardware.

Because the normal register set 16 is utilized for normal operation as well as for conventional interrupts, information that might be corrupted must be stacked from the normal register set 16 as the first operation of the conventional interrupt handler routine. But because the alternate register set 18 is only utilized for fast interrupts, information does not have to be stacked from the alternate register set 18 for the first fast interrupt which is processed. However once a fast interrupt is being processed utilizing the alternate register set 18, there is recursion jeopardy because a fast interrupt with a higher priority might interrupt the present fast interrupt and thus try to use the same register set. Therefore, information that might be corrupted must always be stacked from the alternate register set 18 if a higher priority fast interrupt is received and there are already one or more fast interrupts for which processing has not been completed.

As previously stated, the FO status bit 26 indicates if the processing of one or more fast interrupts has been initiated but has not yet been completed. The FO status bit 26 remains set and is not cleared until the processing of all fast interrupts has been completed. The FO status bit 26 thus can be used to determine whether or not there is recursion jeopardy for the alternate register set 18 and the prime registers 22. Stacking of the alternate register set 18 and the prime registers 22 is required when there is both recursion jeopardy and when the incoming interrupt is a fast interrupt. It is optional whether the CPU circuitry itself stacks all or part of the register information or whether the stacking is left for the user to perform using software instructions.

The FF status bit 28 is set only for the "first" fast interrupt, which occurs only when the prior state of the FO status bit 26 is a cleared state indicating that there were no fast interrupts presently pending. Since the FO

status bit 26 will also be set by the first fast interrupt which sets the FF status bit 28, any fast interrupt with a higher priority level which is initiated before the first fast interrupt is completed will cause a recursion jeopardy situation requiring that information from the first fast interrupt which is located in alternate register set 18 be stacked (i.e. transferred to memory stack 50) as the first operation of the interrupt handler routine. Information in the prime registers 22, which includes the FO status bit 26, the FF status bit 28, the CF status bit 30, and the A/N' bit 36, is also stacked. Upon terminating the second fast interrupt operation, the register and status bit information for the first fast interrupt operation will be unstacked (i.e. retrieved from memory stack 50) and the first fast interrupt operation will be resumed. The first fast interrupt will be the only fast interrupt for which the FF status bit 28 is set. During processing of all other fast interrupts, the FF status bit 28 will be cleared. Therefore, the FF status bit 28 can be used to determine whether or not there are any more fast interrupts which are pending and whether or not there is information from one or more fast interrupts remaining on the stack. It is optional whether the CPU 14 circuitry itself unstacks all or part of the register information or whether the unstacking is left for the user to perform using software instructions.

The CF status bit 30 is used to indicate that a fast interrupt is currently being processed. The CF status bit 30 is set when the CPU 14 is currently processing a fast interrupt and is cleared when the fast interrupt is completed or when a higher priority level of conventional interrupt has interrupted a fast interrupt and is currently being processed.

It will of course be understood by those skilled in the art that additional register sets can be provided on semiconductor chip 10 to reduce the requirement to save operations to memory stack 50. However, the problem is that regardless of the number of register sets provided, there may always be one more level of nested interrupts than the extra register sets can accommodate without stacking. It is seldom efficient to provide so many register sets that stacking is not required. If high levels of nesting occur infrequently it is generally much more efficient to provide the two on-chip register sets disclosed and utilize memory stack 50 during nesting. In this instance most of the overhead associated with saving to or restoring from memory stack 50 during interrupt operations will be eliminated, since information in normal register set 16 and/or alternate register set 18 would not need to be saved in memory stack 50 unless nesting occurs.

Expanding this idea to an "N" deep set of registers, the jeopardy for recursion will occur when there has been an "N" deep nesting of interrupts, such that an "N+1" interrupt in the nesting would require that the previous interrupt operation be saved in a memory stack. In this case the first status bit would indicate "at least N deep nested interrupts in process" (or a recursion hazard) and would indicate whether the CPU should switch

to another register bank or whether all of the registers are in use and the CPU must do a more time consuming stacking procedure before using a register bank. The second status bit would indicate which interrupt was the "first interrupt" so that the CPU would know when there were no more interrupts pending. Additional status bits could be optionally used if there were multiple types of interrupts. For example, a third status bit could be used to indicate whether the CPU was currently processing a conventional or a fast interrupt. The manipulation of these bits will remain the same, such that for the first interrupt, the "first interrupt" status bit will be set, and upon the N<sup>th</sup> nesting, the "recursion hazard" status bit will be set. The "recursion hazard" status bit will continue to remain set as long as there are at least "N" deep nested interrupts in process. The "first interrupt" status bit will be cleared by any subsequent interrupts or by completion of the first interrupt which caused the setting of the "first interrupt" status bit.

Referring specifically to FIG. 2, a flow chart for an interrupt nesting example is illustrated. In this example, normal operation is interrupted by a fast interrupt having a priority level "w". Because this is the first fast interrupt, the CPU 14 switches from using the unprime registers 20 to using the prime registers 22. Since alternate register set 18 is utilized for fast interrupt operations and there is presently no recursion jeopardy, the CPU 14 doesn't stack, but instead switches register banks and selects alternate register set 18 prior to the start of the level "w" fast interrupt. Also, since this is the first fast interrupt and since CPU 14 is currently in the fast interrupt mode, FO status bit 26, FF status bit 28, and CF status bit 30 are all set.

Before the level "w" fast interrupt operation can be completed, a fast interrupt having a priority level "x" (which is greater than the priority level w) is requested and subsequently initiated. Alternate register set 18 remains enabled because the incoming interrupt is a fast interrupt. The CPU 14 hardware stacks the information which is associated with the level "w" interrupt from the prime registers 22 to the memory stack 50. The user, in software, has the option of stacking from alternate register set 18 to memory stack 50 any information associated with the level "w" interrupt which might be corrupted by the new interrupt "x". CPU 14 can then start level "x" fast interrupt operation. FF status bit 28 is cleared, since CPU 14 is not processing the the "first fast interrupt" anymore. However, FO status bit 26 and CF status bit 30 remain set because a fast interrupt has been initiated but not completed and CPU 14 is currently processing a fast interrupt.

Before the level "x" fast interrupt operation can be completed, a conventional interrupt having a priority level "y" (which is greater than the priority level x) is requested. The CPU 14 hardware stacks the information which is associated with the level "x" interrupt from the prime registers 22 to the memory stack 50. The CPU switches from using the alternate register set 18 to using

the normal register set 16 because the normal register set 16 is used for all conventional interrupts. The user, in software, has the option of stacking from normal register set 18 to memory stack 50 any information associated with the normal operation which might be corrupted by the new interrupt "y". With the initiation of the level "y" conventional interrupt, CF status bit 30 is cleared because CPU 14 is currently processing a conventional interrupt.

Before the level "y" conventional interrupt operation can be completed, a fast interrupt having a priority level "z" (which is greater than the priority level y) is requested. The CPU 14 hardware stacks the information which is associated with the level "y" interrupt from the prime registers 22 to the memory stack 50. The CPU 14 switches from using the normal register set 16 to using the alternate register set 18 because the alternate register set 18 is used for all fast interrupts. The user, in software, has the option of stacking from alternate register set 18 to memory stack 50 any information associated with the level "x" interrupt which might be corrupted by the new interrupt "z". CPU 14 initiates the level "z" fast interrupt operation and the CF status bit 30 is again set, since CPU 14 is currently processing a fast interrupt.

No additional interrupts are requested and CPU 14 is allowed to complete the level "z" fast interrupt operation. Note that if the user, in software, stacks any information associated with the level "x" fast interrupt operation at the beginning of the level "z" interrupt processing, that information associated with the level "x" fast interrupt operation must be unstacked and restored at the end of the level "z" interrupt processing. Once the level "z" fast interrupt operation has completed, the information associated with the level "y" conventional interrupt operation is unstacked from memory stack 50 and is loaded into prime registers 22. The CF status bit 30 can be used to determine whether a remaining interrupt is a conventional interrupt and should use the normal register set 16, or is a fast interrupt and should use the alternate register set 18. Since the unstacked CF status bit 30 indicates that the next interrupt is a conventional interrupt (level "y") and since the information for this operation is still in normal register set 16, CPU 14 enables normal register set 16 and continues the level "y" conventional interrupt operation.

Before the completion of the level "y" conventional interrupt, the user, in software, must unstack from memory stack 50 to the normal register set 16 any information associated with the normal operation which had been previously stacked. Once the level "y" conventional interrupt has completed, the information saved in memory stack 50 which is associated with the level "x" fast interrupt operation is transferred back to the prime registers 22. Because the unstacked value of the CF status bit 30 indicates that this remaining interrupt is a fast interrupt, the alternate register set 18, which contains information associated with the level "x" fast interrupt operation, is

enabled and the level "x" fast interrupt operation is continued.

At the end of the level "x" interrupt routine, the user, in software, must unstack from memory stack 50 to the alternate register set 18 any information associated with the level "w" fast interrupt operation which had been previously stacked. Once the level "x" fast interrupt operation has completed, the information associated with the level "w" fast interrupt operation is unstacked from memory stack 50 and is loaded into prime registers 22. Since the unstacked CF status bit 30 indicates that the next interrupt is a fast interrupt (level "w") and since the information for this operation is already located in alternate register set 18, CPU 14 keeps alternate register set 18 enabled and continues the level "w" fast interrupt operation. Because the FF status bit 28 is set for the level "w" fast interrupt, it is known that this interrupt is the last remaining fast interrupt in process.

Once the processing of the level "w" first fast interrupt has completed, the CPU 14 switches back to using the unprime registers 20. The first fast interrupt operation does not have to do any stacking because it is always the first process to use both the alternate register set 18 and the prime registers 22. With the completion of the first fast interrupt operation, CPU 14 is free to return to normal operation. Normal register set 16 already contains the information associated with the normal operation and is simply enabled as CPU 14 resumes normal operation.

It should be noted that throughout the above described nesting procedure status bits FO 26, FF 28, and CF 30 were utilized to indicate the present status of CPU 14 and the progress of the nesting procedure. In addition, the correlation between the three status bits, the nesting procedure, and the contents of normal register set 16, alternate register set 18, unprime registers 20, prime registers 22, and memory stack 50 can be appreciated. Thus, it will be seen by those skilled in the art that the contents and operation of normal register set 16, alternate register set 18, unprime registers 20, prime registers 22, and memory stack 50 can be simply and efficiently controlled by use of status bits FO 26, FF 28, and CF 30.

Referring to FIG. 3A and 3B, these figures are two possible state diagram representations for the status bits which can be used to handle recursion jeopardy. FIG. 3A is a state diagram 40 of the preferred embodiment which utilizes an FO status bit 26, an FF status bit 28, and a CF status bit 30 as described in this specification. An arrow represents the occurrence of an interrupt. When the processing of that particular interrupt is completed, the status bits for the prior interrupt are restored and thus the CPU 14 returns to its prior state.

State "000" represents the state in which no fast interrupts are in progress. State "111" represents the state in which only one fast interrupt has occurred and in which the most recent interrupt to occur was a fast interrupt. State "101" represents the state in which more

than one fast interrupt has occurred and in which the most recent interrupt to occur was a fast interrupt. State "110" represents the state in which only one fast interrupt has occurred and in which the most recent interrupt to occur was a conventional interrupt. State "100" represents the state in which more than one fast interrupt has occurred and in which the most recent interrupt to occur was a conventional interrupt. These particular states and corresponding bit representations were chosen for the ease of software programming, but other states and other bit representations are also possible.

Referring to FIG. 3B, the state diagram 50 illustrates that it would also be possible to handle recursion jeopardy using as few as two status bits. Coming out of reset, the two status bits would start in state "00". Conventional interrupts would not cause any change in the status bits, however a fast interrupt would change the value of the status bits to "01". Once in state "01", a fast interrupt would change the value of the status bits to "10", whereas a conventional interrupt would change the value of the status bits to "11". In state "10", a fast interrupt would not change the value of the status bits, but a conventional interrupt would change the value of the status bits to "11". In state "11", a conventional interrupt would not change the value of the status bits, but a fast interrupt would change the value of the status bits to "10". The CPU 14 hardware or the software programmer would always be able to tell whether or not there was recursion jeopardy, whether an interrupt was the first fast interrupt, and whether the most recent interrupt was a fast interrupt or a conventional interrupt by looking at the value of the two status bits. State "00" is the only state in which there is no recursion jeopardy for a fast interrupt. State "01" indicates that the present interrupt is the first fast interrupt. And states "01" and "10" are only for fast interrupts while state "00" and "11" are only for conventional interrupts.

This invention allows the implementation and use of resources which are subject to recursion jeopardy by providing a mechanism to decide: (1) when the recursion problems will occur, such that any further attempts to utilize the resource may be directed to a similar resource not subject to the recursive limitations; and (2) when there is recovery from the jeopardy of an immediate recursion problem, such that the resource which did have the potential of recursion problems may again be utilized. This allows the implementation of resources which, although subject to recursion jeopardy, provide a higher performance solution than the secondary resource which does not have the recursion jeopardy. Further, because of the present invention, apparatus may be structured such that the high performance resource has sufficient depth to provide an overall system performance enhancement, while still solving the more exceptional case of a recursion jeopardy.

## Claims

## 1. A digital data processor comprising:

a bus;  
 a first register set (16,20) coupled to the bus;  
 a second register (18,22) set coupled to the bus;  
 a first status bit (26) coupled to the bus;  
 a second status bit (28) coupled to the bus;  
 central processing unit means coupled to the bus for utilizing said first and second register sets one at a time;  
 first interrupt receiving means coupled to the central processing unit and to a first interrupt request signal conductor for receiving interrupt requests of a first type;

characterized by:

second interrupt receiving means coupled to the central processing unit and to a second interrupt request signal conductor for receiving interrupt requests of a second type;  
 state determining means coupled to the first and second status bits and the first and second interrupt receiving means for determining, in response to receipt of an interrupt request by either the first or second interrupt receiving means, whether the interrupt request is of the first type or the second type, whether the first status bit is in a first state or a second state and whether the second status bit is in the first state or the second state; and  
 register set selecting means coupled to the state determining means and to the central processing unit means for selecting, in response to receipt of an interrupt request by either the first or second interrupt receiving means, one of the first and second register sets for utilization by the central processing unit means, the selection by the register set selecting means is dependent upon determinations of the state determining means.

## 2. A digital data processor according to claim 1 further comprising:

next state determining means coupled to the first and second status bits and the first and second interrupt receiving means for determining, in response to receipt of an interrupt request by either the first or second interrupt receiving means, new values of the first and second status bits.

## 3. A digital data processor according to claim 2 further comprising:

a first control bit coupled to the bus and to the register set selecting means, a state of the first con-

trol bit indicates which of the first and second register sets is presently being utilized by the central processing unit means and the central processing unit means is capable of determining the state of the first control bit independent of the register set selecting means.

## 4. A digital data processor according to claim 2 further comprising:

a third status bit coupled to the bus; and  
 wherein the first, second and third status bits, taken together, indicate one of:  
 that no interrupt request of the second type has been received that has not been completed;  
 that only one interrupt request of the second type has been received and that a most recent interrupt request received was of the second type;  
 that more than one interrupt request of the second type has been received and that a most recent interrupt request received was of the second type; and  
 that at least one of the second type of interrupt request has been received and that a most recent interrupt request received was of the first type.

## 5. A digital data processor comprising:

a bus;  
 a first register set coupled to the bus, the first register set further comprising:  
 a first register subset (20); and  
 a second register subset (16);  
 a second register set coupled to the bus, the second register set further comprising:  
 a third register subset (22); and  
 a fourth register subset (18);  
 a first status bit coupled to the bus;  
 a second status bit coupled to the bus;  
 central processing unit means coupled to the bus for utilizing said first and second register sets one at a time;  
 first interrupt receiving means coupled to the central processing unit and to a first interrupt request signal conductor for receiving interrupt requests of a first type;

characterized by:

second interrupt receiving means coupled to the central processing unit and to a second interrupt request signal conductor for receiving interrupt requests of a second type;  
 state determining means coupled to the first and second status bits and the first and second interrupt receiving means for determining, in re-



sponse to receipt of an interrupt request by either the first or second interrupt receiving means, whether the interrupt request is of the first type or the second type, whether the first status bit is in a first state or a second state and whether the second status bit is in the first state or the second state; and

register set selecting means coupled to the state determining means and to the central processing unit means for selecting, in response to receipt of an interrupt request by either the first or second interrupt receiving means, one of the first and third register subsets and one of the second and fourth register subsets for utilization by the central processing unit means, the selection by the register set selecting means is dependent upon determinations of the state determining means.

6. A method of operating a digital data processor comprising the steps of:

conducting non-interrupt processing utilizing a first register set;  
receiving interrupt requests of a first type;  
conditionally halting said non-interrupt processing and beginning interrupt processing upon receipt of an interrupt request of the first type;

wherein the method is characterized by the further steps of:

receiving interrupt requests of a second type;  
conditionally halting said non-interrupt processing and beginning interrupt processing upon receipt of an interrupt request of the second type;  
setting and clearing first and second status bits dependent upon:  
whether an interrupt request of the second type has been received and not completed; and  
whether an interrupt request of the second type is presently being processed; and  
selecting one of the first register set and an alternate register set upon beginning interrupt processing, a result of the step of selecting is dependent upon whether the beginning of interrupt processing was caused by an interrupt request of the first type or of the second type and upon states of the first and second status bits.

7. A method according to claim 6 further comprising the steps of:

setting and clearing the first and second status bits dependent upon:

whether an interrupt presently being processed is of the second type and is the only such interrupt request of the second type which has been received and not completed.

8. A method according to claim 7 wherein the step of selecting one of the first register set and the second register set further comprises the steps of:

selecting one of a first and third register subsets and one of a second and fourth register subsets.

9. A method according to claim 8 wherein the step of selecting one of the first register set and the second register set further comprises the step of:

always selecting the third register subset after a first interrupt request of the second type has been received and before the first interrupt request of the second type has been completed.

10. A method according to claim 8 wherein the step of selecting one of the first register set and the second register set further comprises the step of:

always selecting the fourth register subset while the central processing unit means is processing an interrupt request of the second type.

#### Patentansprüche

1. Digitaler Datenprozessor mit:

einem Bus;

einem ersten Registersatz (16, 20), der mit dem Bus verbunden ist;

einem zweiten Registersatz (18, 22), der mit dem Bus verbunden ist;

einem ersten Statusbit (26), das mit dem Bus verbunden ist;

einem zweiten Statusbit (28), das mit dem Bus verbunden ist;

einer zentralen Verarbeitungseinheit, die mit dem Bus verbunden ist, zum Benutzen des ersten und zweiten Registersatzes zu jeweiligen Zeiten;

einer ersten Unterbrechungsempfangeinrichtung, die mit der zentralen Verarbeitungseinheit und mit einem ersten Unterbrechungsanforderungssignalleiter verbunden ist, zum Empfangen von Unterbrechungsanforderungen eines ersten Typs;

gekennzeichnet durch:

eine zweite Unterbrechungsempfangseinrichtung, die mit der zentralen Verarbeitungseinheit und mit einem zweiten Unterbrechungsanforderungssignalleiter verbunden ist, zum Empfangen von Unterbrechungsanforderungen eines zweiten Typs;

einer Zustandsbestimmungseinrichtung, die mit dem ersten und zweiten Statusbit und der ersten und zweiten Unterbrechungsempfangseinrichtung verbunden ist, zum Bestimmen, ob die Unterbrechungsanforderung vom ersten Typ oder vom zweiten Typ ist, ob das erste Statusbit in einem ersten Zustand oder einem zweiten Zustand ist, und ob das zweite Statusbit in dem ersten Zustand oder dem zweiten Zustand ist, als Reaktion auf den Empfang einer Unterbrechungsanforderung durch entweder die erste oder zweite Unterbrechungsempfangseinrichtung; und

einer Registersatz-Auswahleinrichtung, die mit der Zustandsbestimmungseinrichtung und der zentralen Verarbeitungseinheit verbunden ist, zum Auswählen eines des ersten und zweiten Registersatzes zur Benutzung durch die zentrale Verarbeitungseinheit als Reaktion auf den Empfang einer Unterbrechungsanforderung durch entweder die erste oder zweite Unterbrechungsempfangseinrichtung, wobei die Auswahl durch die Registersatz-Auswahleinrichtung von den Bestimmungen der Zustandsbestimmungseinrichtung abhängig ist.

2. Digitaler Datenprozessor nach Anspruch 1, gekennzeichnet durch:

eine Folgezustands-Bestimmungseinrichtung, die mit dem ersten und zweiten Statusbit und der ersten und zweiten Unterbrechungsempfangseinrichtung verbunden ist, zum Bestimmen neuer Werte des ersten und zweiten Statusbits als Reaktion auf den Empfang einer Unterbrechungsanforderung durch entweder die erste oder zweite Unterbrechungsempfangseinrichtung.

3. Digitaler Datenprozessor nach Anspruch 2, gekennzeichnet durch:

ein erstes Steuerbit, das mit dem Bus und der Registersatz-Auswahleinrichtung verbunden ist, wobei der Zustand des ersten Steuerbits anzeigt, welcher des ersten und zweiten Registersatzes momentan durch die zentrale Verarbeitungseinheit benutzt wird, und die zentrale Verarbeitungseinheit in der Lage ist, den Zustand des ersten Steuerbits unabhängig von der Registersatz-Auswahleinrichtung zu bestimmen.

4. Digitaler Datenprozessor nach Anspruch 2, gekennzeichnet durch:

ein drittes Statusbit, das mit dem Bus verbunden ist; und

wobei das erste, zweite und dritte Statusbit zusammengenommen eine der folgenden Anzeigen bilden:

daß keine Unterbrechungsanforderung des zweiten Typs empfangen wurde, die nicht vervollständigt ist;

daß nur eine Unterbrechungsanforderung des zweiten Typs empfangen wurde und daß eine jüngste empfangene Unterbrechungsanforderung vom zweiten Typ war;

daß mehr als eine Unterbrechungsanforderung des zweiten Typs empfangen wurde und daß eine jüngste empfangene Unterbrechungsanforderung vom zweiten Typ war; und

daß zumindest eine Unterbrechungsanforderung vom zweiten Typ empfangen wurde und daß eine jüngste empfangene Unterbrechungsanforderung vom ersten Typ war.

5. Digitaler Datenprozessor mit:

einem Bus;

einem ersten Registersatz, der mit dem Bus verbunden ist, wobei der erste Registersatz weiterhin aufweist:

einen ersten Registeruntersatz (20); und

einen zweiten Registeruntersatz (16);

einem zweiten Registersatz, der mit dem Bus verbunden ist, wobei der zweite Registersatz weiterhin aufweist:

einen dritten Registeruntersatz (22); und

einen vierten Registeruntersatz (18);

einem ersten Statusbit, das mit dem Bus verbunden ist;

einem zweiten Statusbit, das mit dem Bus verbunden ist;

einer zentralen Verarbeitungseinheit, die mit dem Bus verbunden ist, zum Benutzen des ersten und zweiten Registersatzes zu jeweiligen

Zeiten;

einer ersten Unterbrechungsempfangseinrichtung, die mit der zentralen Verarbeitungseinheit und mit einem ersten Unterbrechungsanforderungssignalleiter verbunden ist, zum Empfangen der Unterbrechungsanforderungen eines ersten Typs;

gekennzeichnet durch:

eine zweite Unterbrechungsempfangseinrichtung, die mit der zentralen Verarbeitungseinheit und mit einem zweiten Unterbrechungsanforderungssignalleiter verbunden ist, zum Empfangen von Unterbrechungsanforderungen eines zweiten Typs;

eine Zustandsbestimmungseinrichtung, die mit dem ersten und zweiten Statusbit und der ersten und zweiten Unterbrechungsempfangseinrichtung verbunden ist, zum Bestimmen, ob die Unterbrechungsanforderung vom ersten Typ oder vom zweiten Typ ist, ob das erste Statusbit in einem ersten Zustand oder einem zweiten Zustand ist, und ob das zweite Statusbit im ersten Zustand oder im zweiten Zustand ist, als Reaktion auf den Empfang einer Unterbrechungsanforderung durch entweder die erste oder die zweite Unterbrechungsempfangseinrichtung; und

eine Registersatz-Auswahleinrichtung, die mit der Zustandsbestimmungseinrichtung und mit der zentralen Verarbeitungseinheit verbunden ist, zum Auswählen, eines des ersten und dritten Registeruntersatzes und eines des zweiten und vierten Registersatzes zur Benutzung durch die zentrale Verarbeitungseinheit als Reaktion auf den Empfang einer Unterbrechungsanforderung durch entweder die erste oder die zweite Unterbrechungsempfangseinrichtung, wobei die Auswahl durch die Registersatz-Auswahleinrichtung von den Bestimmungen der Zustandsbestimmungseinrichtung abhängig ist.

6. Verfahren zum Betreiben eines digitalen Datenprozessors mit den Schritten:

Durchführen einer Nicht-Unterbrechungs-Verarbeitung unter Benutzung eines ersten Registersatzes;

Empfangen von Unterbrechungsanforderungen eines ersten Typs;

bedingtes Unterbrechen der Nicht-Unterbre-

chungs-Verarbeitung und Beginnen einer Unterbrechungsverarbeitung beim Empfang einer Unterbrechungsanforderung des ersten Typs;

wobei das Verfahren durch folgende weitere Schritte gekennzeichnet ist:

Empfangen von Unterbrechungsanforderungen eines zweiten Typs;

bedingtes Unterbrechen der Nicht-Unterbrechungs-Verarbeitung und Beginnen der Unterbrechungsverarbeitung beim Empfang einer Unterbrechungsanforderung des zweiten Typs;

Setzen und Löschen eines ersten und zweiten Statusbits abhängig davon,

ob eine Unterbrechungsanforderung des zweiten Typs empfangen wurde und nicht vervollständigt ist;

ob eine Unterbrechungsanforderung des zweiten Typs momentan verarbeitet wird; und

Auswählen von einem des Registersatzes und eines alternativen Registersatzes beim Beginn der Unterbrechungsverarbeitung, wobei ein Resultat des Auswahlverfahrens davon abhängt, ob der Beginn der Unterbrechungsverarbeitung durch eine Unterbrechungsanforderung des ersten Typs oder des zweiten Typs bewirkt wurde, und von Zuständen des ersten und zweiten Statusbits.

7. Verfahren nach Anspruch 6, gekennzeichnet durch folgende Schritte:

Setzen und Löschen des ersten und zweiten Statusbits abhängig davon,

ob eine Unterbrechung, die momentan verarbeitet wird, vom zweiten Typ ist und die einzige solche Unterbrechungsanforderung des zweiten Typs ist, die empfangen wurde und nicht vervollständigt wurde.

8. Verfahren nach Anspruch 7, dadurch gekennzeichnet, daß der Schritt des Auswählens von einem des ersten Registersatzes und des zweiten Registersatzes weiterhin folgende Schritte aufweist: Auswählen von einem eines ersten und eines dritten Registeruntersatzes und von einem eines zweiten und vierten Registeruntersatzes.

9. Verfahren nach Anspruch 8, dadurch gekennzeichnet, daß der Schritt des Auswählens des ersten Registersatzes und des zweiten Registersatzes wei-

terhin folgenden Schritt aufweist:  
 stets Auswählen des dritten Registeruntersatzes,  
 nachdem eine erste Unterbrechungsanforderung  
 des zweiten Typs empfangen wurde und bevor die  
 erste Unterbrechungsanforderung des zweiten 5  
 Typs vervollständigt wurde.

10. Verfahren nach Anspruch 8, dadurch gekennzeichnet, daß der Schritt des Auswählens von einem des ersten Registersatzes und des zweiten Registersatzes weiterhin folgenden Schritt aufweist:  
 stets Auswählen des vierten Registeruntersatzes,  
 während die zentrale Verarbeitungseinheit eine Unterbrechungsanforderung des zweiten Typs verarbeitet.

### Revendications

1. Processeur de données numériques comprenant : 20
- un bus ;
  - un premier jeu de registres (16, 20) couplés au bus ;
  - un second jeu de registres (18, 22) couplés au bus ; 25
  - un premier bit d'état (26) couplé au bus ;
  - un second bit d'état (28) couplé au bus ;
  - un moyen d'unité centrale de traitement couplé au bus pour utiliser lesdits premier et second 30 jeux de registres à raison d'un à la fois ;
  - un premier moyen de réception d'interruption couplé à l'unité centrale de traitement ainsi qu'à un premier conducteur de signal de requête d'interruption pour recevoir des requêtes d'in- 35 terruption d'un premier type,
- caractérisé par :
- un second moyen de réception d'interruption couplé à l'unité centrale de traitement ainsi qu'à un second conducteur de signal de requête d'interruption pour recevoir des requêtes d'in- 40 terruption d'un second type ;
  - un moyen de détermination d'état couplé aux premier et second bits d'état et aux premier et second moyens de réception d'interruption pour déterminer, en réponse à la réception d'une requête d'interruption par soit le premier, soit le second moyen de réception d'interrup- 45 tion, si la requête d'interruption est du premier type ou du second type, si le premier bit d'état est dans un premier état ou un second état et si le second bit d'état est dans le premier état ou le second état ; et 50
  - un moyen de sélection de jeu de registres couplé au moyen de détermination d'état et au moyen d'unité centrale de traitement pour sé-

lectionner, en réponse à une réception d'une requête d'interruption par soit le premier, soit le second moyen de réception d'interruption, l'un des premier et second jeux de registres en vue d'une utilisation par le moyen d'unité centrale de traitement, la sélection par le moyen de sélection de jeu de registres dépendant de détermi-  
 nations du moyen de détermination d'état.

2. Processeur de données numériques selon la revendication 1, comprenant en outre :

un moyen de détermination d'état suivant couplé aux premier et second bits d'état ainsi qu'aux premier et second moyens de réception d'interruption pour déterminer, en réponse à la réception d'une requête d'interruption par soit le premier moyen de réception d'interruption, soit le second, de nouvelles valeurs des premier et second bits d'état.

3. Processeur de données numériques selon la revendication 2, comprenant en outre :

un premier bit de commande couplé au bus et au moyen de sélection de jeu de registres, un état du premier bit de commande indiquant lequel des premier et second jeux de registres est en train d'être présentement utilisé par le moyen d'unité centrale de traitement et le moyen d'unité centrale de traitement pouvant déterminer l'état du premier bit de commande indépendamment du moyen de sélection de jeu de registres.

4. Processeur de données numériques selon la revendication 2, comprenant en outre :

un troisième bit d'état couplé au bus ; et dans lequel les premier, second et troisième bits d'état considérés ensemble indiquent une situation prise parmi :

il n'y a pas de requête d'interruption du second type reçue qui n'a pas été terminée ;  
 seulement une requête d'interruption du second type a été reçue et une requête d'interruption la plus récente reçue était du second type ;  
 plus d'une requête d'interruption du second type a été reçue et une requête d'interruption la plus récente reçue était du second type ; et  
 au moins une requête d'interruption du second type a été reçue et une requête d'interruption la plus récente reçue était du premier type.

5. Processeur de données numériques comprenant :

un bus ;  
 un premier jeu de registres couplés au bus, le premier jeu de registres comprenant en outre :  
 un premier sous-jeu de registres (20) ; et  
 un second sous-jeu de registres (16) ;

un second jeu de registres couplés au bus, le second jeu de registres comprenant en outre :  
 un troisième sous-jeu de registres (22) ; et  
 un quatrième sous-jeu de registres (18) ;  
 un premier bit d'état couplé au bus ;  
 un second bit d'état couplé au bus ;  
 un moyen d'unité centrale de traitement couplé au bus pour utiliser lesdits premier et second jeux de registres à raison d'un à la fois ;  
 un premier moyen de réception d'interruption couplé à l'unité centrale de traitement ainsi qu'à un premier conducteur de signal de requête d'interruption pour recevoir des requêtes d'interruption d'un premier type,

caractérisé par :

un second moyen de réception d'interruption couplé à l'unité centrale de traitement ainsi qu'à un second conducteur de signal de requête d'interruption pour recevoir des requêtes d'interruption d'un second type ;  
 un moyen de détermination d'état couplé aux premier et second bits d'état et aux premier et second moyens de réception d'interruption pour déterminer, en réponse à la réception d'une requête d'interruption par soit le premier, soit le second moyen de réception d'interruption, si la requête d'interruption est du premier type ou du second type, si le premier bit d'état est dans un premier état ou un second état et si le second bit d'état est dans le premier état ou le second état ; et  
 un moyen de sélection de jeu de registres couplé au moyen de détermination d'état et au moyen d'unité centrale de traitement pour sélectionner, en réponse à une réception d'une requête d'interruption par soit le premier, soit le second moyen de réception d'interruption, l'un des premier et troisième sous-jeux de registres et l'un des second et quatrième sous-jeux de registres en vue d'une utilisation par le moyen d'unité centrale de traitement, la sélection par le moyen de sélection de jeu de registres dépendant de déterminations du moyen de détermination d'état.

6. Procédé d'activation d'un processeur de données numériques comprenant les étapes de :

mise en oeuvre d'un traitement de non interruption en utilisant un premier jeu de registres ;  
 réception de requêtes d'interruption d'un premier type ;  
 arrêt conditionnel dudit traitement de non interruption et démarrage d'un traitement d'interruption suite à la réception d'une requête d'interruption du premier type,

dans lequel le procédé est caractérisé par les étapes supplémentaires de :

réception de requêtes d'interruption d'un second type ;  
 arrêt conditionnel dudit traitement de non interruption et démarrage d'un traitement d'interruption suite à la réception d'une requête d'interruption du second type ;  
 établissement et remise à zéro de premier et second bits d'état en fonction de :  
 si une requête d'interruption du second type a été reçue et non terminée ; et  
 si une requête d'interruption du second type est présentement en train d'être traitée ; et  
 sélection de soit le premier jeu de registres, soit un jeu de registres alternatifs suite au démarrage d'un traitement d'interruption, un résultat de l'étape de sélection dépendant de si le démarrage d'un traitement d'interruption a été provoqué par une requête d'interruption du premier type ou du second type et d'états des premier et second bits d'état.

7. Procédé selon la revendication 6, comprenant en outre les étapes de :

établissement et remise à zéro des premier et second bits d'état en fonction de :  
 si une interruption qui est présentement en train d'être traitée est du second type et est la seule requête d'interruption du second type qui a été reçue et non terminée.

8. Procédé selon la revendication 7, dans lequel l'étape de sélection de soit le premier jeu de registres, soit le second jeu de registres comprend en outre les étapes de :

sélection de l'un de premier et troisième sous-jeux de registres et de l'un de second et quatrième sous-jeux de registres.

9. Procédé selon la revendication 8, dans lequel l'étape de sélection de soit le premier jeu de registres, soit le second jeu de registres comprend en outre l'étape de :

sélection toujours du troisième sous-jeu de registres après qu'une première requête d'interruption du second type a été reçue et avant que la première requête d'interruption du second type n'ait été terminée.

10. Procédé selon la revendication 8, dans lequel l'étape de sélection de soit le premier jeu de registres, soit le second jeu de registres comprend en outre l'étape de :

sélection toujours du quatrième sous-jeu de registres tandis que le moyen d'unité centrale de traitement est en train de traiter une requête d'inter-

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ruption du second type.

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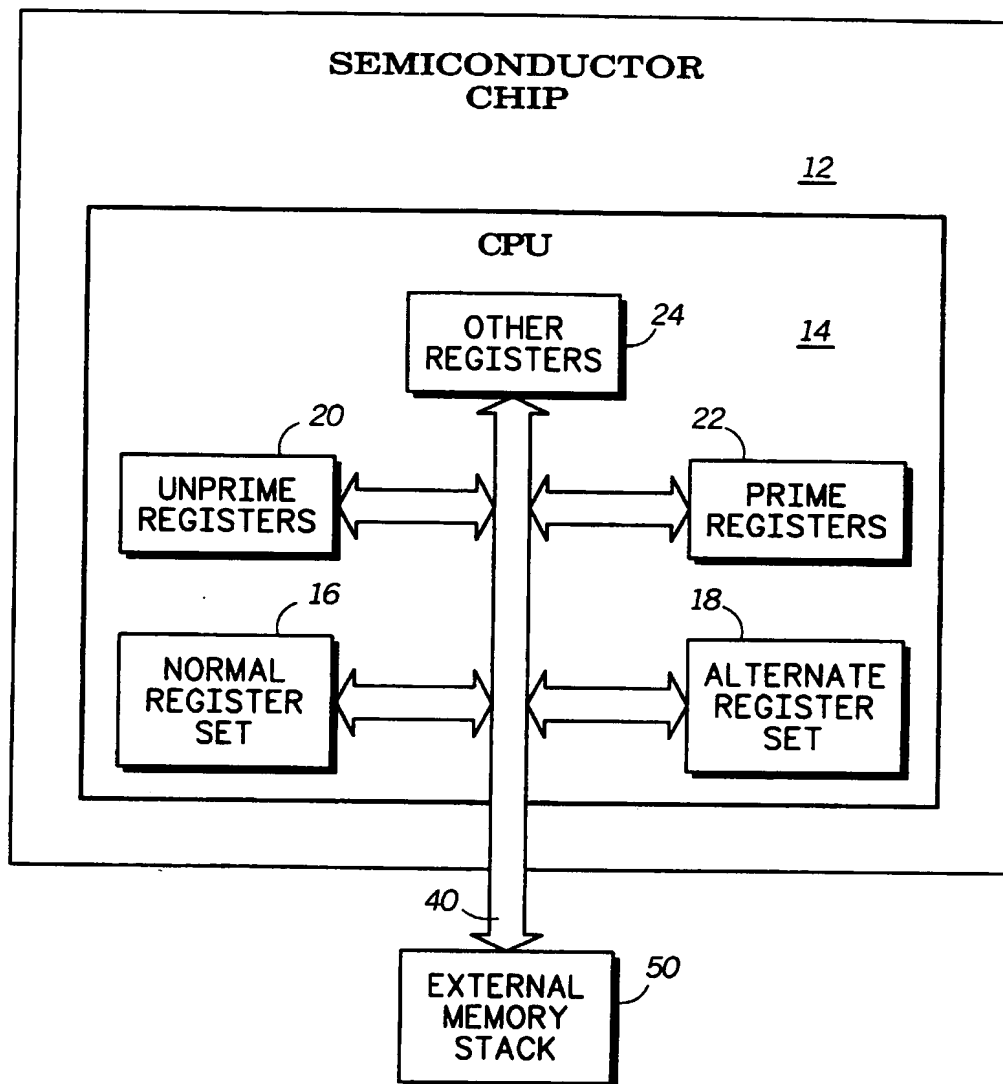
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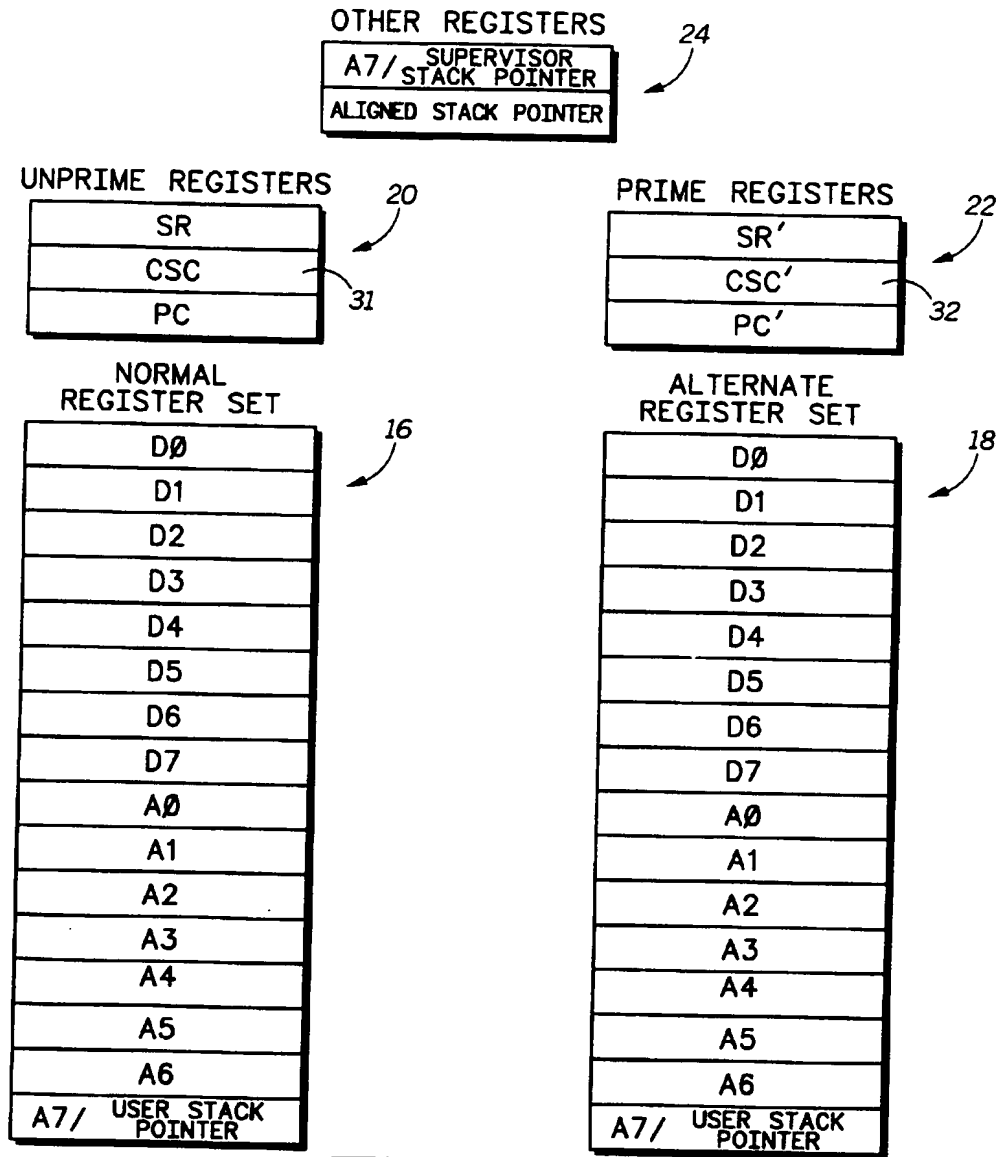
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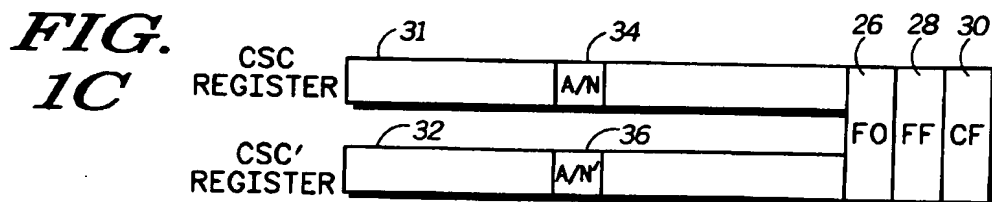
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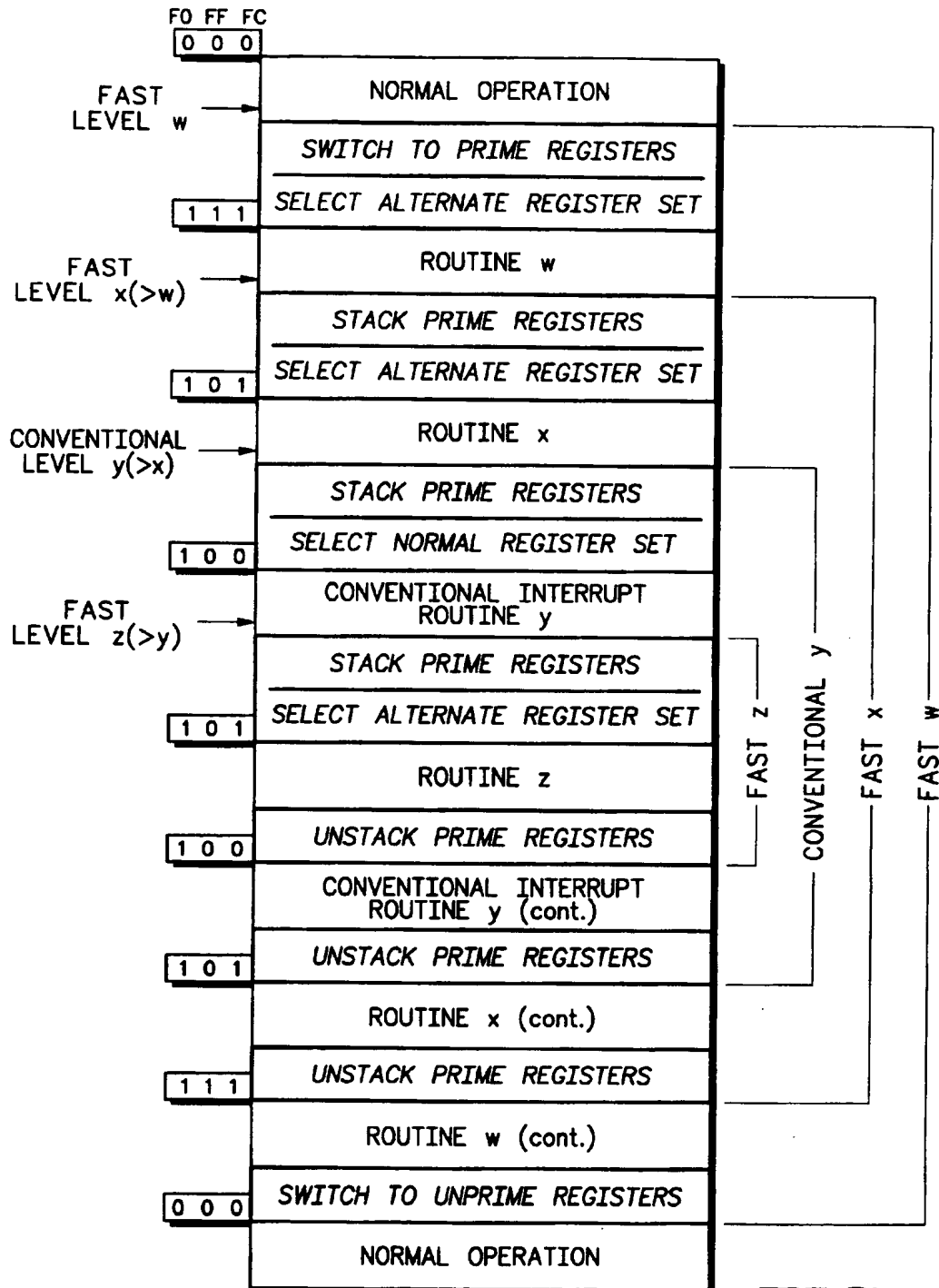
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**FIG. 1A**

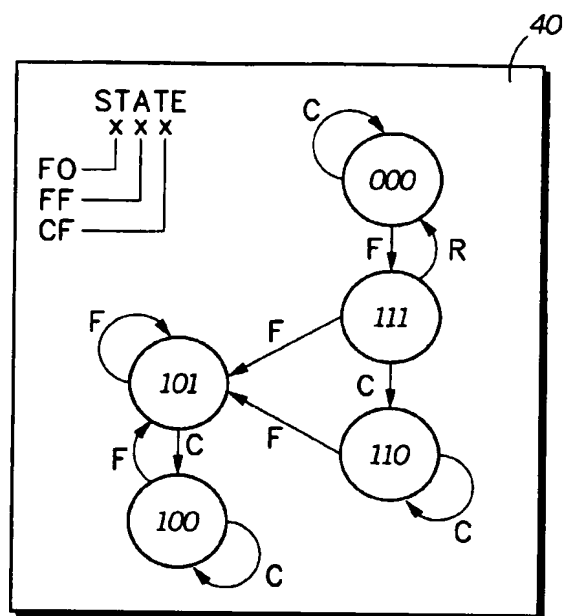


**FIG. 1B**

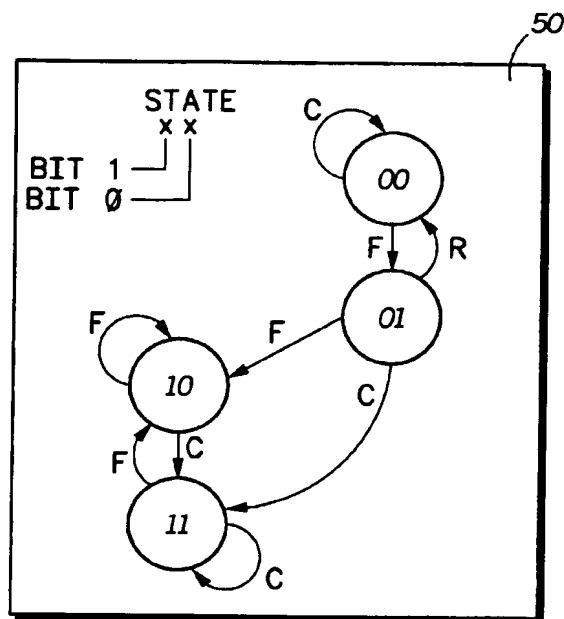




**FIG.2**



**FIG.3A**



**FIG.3B**